

WHAT IS CLAIMED IS:

1                   1. A magnetoresistive head comprising:  
2                   an antiferromagnetic layer;  
3                   a pinned layer formed on the antiferromagnetic layer with a magnetizing  
4 direction of the pinned layer being fixed;  
5                   a nonmagnetic layer formed on the pinned layer;  
6                   a free layer formed on the nonmagnetic layer;  
7                   a magnetic domain control film for magnetic domain control of the free layer;  
8                   and a pair of electrode films for supplying electric current to a stack of the  
9 antiferromagnetic layer, the pinned layer, the nonmagnetic layer, and the free layer;  
10                  wherein, when a width of the free layer as viewed from an air bearing surface  
11 is defined as a geometrical track width  $Twr\_geo(nm)$  and expressed as  $x$ , a magnetization  
12 film thickness product  $Br \cdot t(G \cdot \mu m)$  of the magnetic domain control film and  $x$  satisfy the  
13 following:  
14  $-2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x + 116 \leq Br \cdot t < 3.75 \cdot 10^{-1}x + 130$  and  $40 \leq x < 160$ .

1                   2. A magnetoresistive head comprising:  
2                   an antiferromagnetic layer;  
3                   a pinned layer formed on the antiferromagnetic layer with a magnetizing  
4 direction of the pinned layer being fixed;  
5                   a nonmagnetic layer formed on the pinned layer;  
6                   a free layer formed on the nonmagnetic layer;  
7                   a magnetic domain control film for magnetic domain control of the free layer;  
8 and  
9                   a pair of electrode films for supplying electric current to a stack of the  
10 antiferromagnetic layer, the pinned layer, the nonmagnetic layer, and the free layer;  
11                  wherein, when a width of the free layer as viewed from an air bearing surface  
12 is defined as a geometrical track width  $Twr\_geo(nm)$  and expressed as  $x$ , a magnetization  
13 film thickness product  $Br \cdot t(G \cdot \mu m)$  of the magnetic domain control film and  $x$  satisfy the  
14 following:  
15  $-2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x + 116 \leq Br \cdot t \leq -2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x +$   
16  $141, Br \cdot t < 3.75 \cdot 10^{-1}x + 130$ , and  $40 \leq x < 160$ .

3. A magnetoresistive head comprising:  
 an antiferromagnetic layer;  
 a pinned layer formed on the antiferromagnetic layer with a magnetizing  
 direction of the pinned layer being fixed;  
 a nonmagnetic layer formed on the pinned layer;  
 a free layer formed on the nonmagnetic layer;  
 a magnetic domain control film for magnetic domain control of the free layer;  
 and  
 a pair of electrode films for supplying electric current to a stack of the  
 antiferromagnetic layer, the pinned layer, the nonmagnetic layer, and the free layer;  
 wherein, when a width of the free layer as viewed from an air bearing surface  
 is defined as a geometrical track width  $Twr\_geo(nm)$  and expressed as  $x$ , a magnetization  
 film thickness product  $Br \cdot t (G \cdot \mu m)$  of the magnetic domain control film and  $x$  satisfy the  
 following:  
 $-2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x + 151 \leq Br \cdot t < 3.75 \cdot 10^{-1}x + 165$  and  $40 \leq x < 160$ .

4. A magnetoresistive head comprising:  
 an antiferromagnetic layer;  
 a pinned layer formed on the antiferromagnetic layer with a magnetizing  
 direction of the pinned layer being fixed;  
 a nonmagnetic layer formed on the pinned layer;  
 a free layer formed on the nonmagnetic layer;  
 a magnetic domain control film for magnetic domain control of the free layer;  
 and  
 a pair of electrode films for supplying electric current to a stack of the  
 antiferromagnetic layer, the pinned layer, the nonmagnetic layer, and the free layer;  
 wherein, when a width of the free layer as viewed from an air bearing surface  
 is defined as a geometrical track width  $Twr\_geo(nm)$  and expressed as  $x$ , a magnetization  
 film thickness product  $Br \cdot t (G \cdot \mu m)$  of the magnetic domain control film and  $x$  satisfy the  
 following:  
 $-2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x + 151 \leq Br \cdot t \leq -2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x +$   
 $176, Br \cdot t < 3.75 \cdot 10^{-1}x + 165$ , and  $40 \leq x < 160$ .

5. A magnetoresistive head comprising:  
 an underlying layer;  
 a free layer formed on the underlying layer;  
 a magnetic domain control film for magnetic domain control of the free layer;  
 a nonmagnetic layer formed on the free layer;  
 a pinned layer formed on the nonmagnetic layer with a magnetizing direction  
 of the pinned layer being fixed;  
 an antiferromagnetic layer fixing magnetization of the pinned layer; and  
 a pair of electrode films for supplying electric current to a stack of the  
 underlying layer, the free layer, the nonmagnetic layer, the pinned layer and the  
 antiferromagnetic layer;  
 wherein, when a width of the free layer as viewed from an air bearing surface  
 is defined as a geometrical track width  $Twr\_geo(nm)$  and expressed as  $x$ , a magnetization  
 film thickness product  $Br \cdot t(G \cdot \mu m)$  of the magnetic domain control film and  $x$  satisfy the  
 following:  
 $-2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x + 116 \leq Br \cdot t < 3.75 \cdot 10^{-1}x + 130$  and  $40 \leq x < 160$ .

6. A magnetoresistive head comprising:  
 an underlying layer;  
 a free layer formed on the underlying layer;  
 a magnetic domain control film for magnetic domain control of the free layer;  
 a nonmagnetic layer formed on the free layer;  
 a pinned layer formed on the nonmagnetic layer with a magnetizing direction  
 of the pinned layer being fixed;  
 an antiferromagnetic layer fixing magnetization of the pinned layer; and  
 a pair of electrode films for supplying electric current to a stack of the  
 underlying layer, the free layer, the nonmagnetic layer, the pinned layer and the  
 antiferromagnetic layer;  
 wherein, when a width of the free layer as viewed from an air bearing surface  
 is defined as a geometrical track width  $Twr\_geo(nm)$  and expressed as  $x$ , a magnetization  
 film thickness product  $Br \cdot t(G \cdot \mu m)$  of the magnetic domain control film and  $x$  satisfy the  
 following:

16  $-2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x + 116 \leq Br \cdot t \leq -2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x +$   
17  $141, Br \cdot t < 3.75 \cdot 10^{-1}x + 130, \text{ and } 40 \leq x < 160.$

1 7. A magnetoresistive head comprising:  
2 an underlying layer;  
3 a free layer formed on the underlying layer;  
4 a magnetic domain control film for magnetic domain control of the free layer;  
5 a nonmagnetic layer formed on the free layer;  
6 a pinned layer formed on the nonmagnetic layer with a magnetizing direction  
7 of the pinned layer being fixed;  
8 an antiferromagnetic layer fixing magnetization of the pinned layer; and  
9 a pair of electrode films for supplying electric current to a stack of the  
10 underlying layer, the free layer, the nonmagnetic layer, the pinned layer and the  
11 antiferromagnetic layer;  
12 wherein, when a width of the free layer as viewed from an air bearing surface  
13 is defined as a geometrical track width  $Twr\_geo(nm)$  and expressed as  $x$ , a magnetization  
14 film thickness product  $Br \cdot t(G \cdot \mu m)$  of the magnetic domain control film and  $x$  satisfy the  
15 following:  
16  $-2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x + 151 \leq Br \cdot t < 3.75 \cdot 10^{-1}x + 165$  and  $40 \leq x < 160.$

1 8. A magnetoresistive head comprising:  
2 an underlying layer;  
3 a free layer formed on the underlying layer;  
4 a magnetic domain control film for magnetic domain control of the free layer;  
5 a nonmagnetic layer formed on the free layer;  
6 a pinned layer formed on the nonmagnetic layer with a magnetizing direction  
7 of the pinned layer being fixed;  
8 an antiferromagnetic layer fixing magnetization of the pinned layer; and  
9 a pair of electrode films for supplying electric current to a stack of the  
10 underlying layer, the free layer, the nonmagnetic layer, the pinned layer and the  
11 antiferromagnetic layer;  
12 wherein, when a width of the free layer as viewed from an air bearing surface  
13 is defined as a geometrical track width  $Twr\_geo(nm)$  and expressed as  $x$ , a magnetization

14 film thickness product  $Br \cdot t$  ( $G \cdot \mu m$ ) of the magnetic domain control film and  $x$  satisfy the  
15 following:

16  $-2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x + 151 \leq Br \cdot t \leq -2.94 \cdot 10^{-4}x^3 + 8.54 \cdot 10^{-2}x^2 - 5.73x +$   
17  $176,$

18  $Br \cdot t < 3.75 \cdot 10^{-1}x + 165,$  and  $40 \leq x < 160.$

1 9. A magnetoresistive head comprising:  
2 an insulative layer formed on a substrate;  
3 an antiferromagnetic layer formed on the insulative layer;  
4 a pinned layer formed on the antiferromagnetic layer with a magnetizing  
5 direction of the pinned layer being fixed;  
6 a nonmagnetic layer formed on the pinned layer;  
7 a free layer formed on the nonmagnetic layer;  
8 a pair of electrode films for supplying electric current to a stack of the  
9 antiferromagnetic layer, the pinned layer, the nonmagnetic layer and the free layer; and  
10 an electrode underlying film;  
11 wherein the electrode underlying film is formed directly on the insulative film  
12 in a case where a width of the free layer as viewed from an air bearing surface is defined as  
13  $Twr\_geo$  (nm) and expressed as  $x$ , and  $x < 40.$

1 10. A magnetoresistive head according to any one of claims 1 to 8, wherein  
2 the magnetic domain control film comprises a magnetic film made of a CoPt alloy  
3 comprising at least 4 to 30 at% of Pt, or a CoCrPt alloy, or CoCrPt-ZrO<sub>2</sub> or CoCrPt-SiO<sub>2</sub>  
4 further comprising 2 to 15 at% of Cr.

1 11. A magnetoresistive head according to any one of claims 1 to 8, wherein  
2 the magnetic domain control film comprises a stacked film in which at least two or more  
3 magnetic films are antiferromagnetically coupled by way of a nonmagnetic film comprising  
4 Ru, Cr, Ir, Rh, Os, Re, Au, Ag, Cu or an alloy thereof, and a magnetic film as a constituent  
5 element thereof is a magnetic film comprising a CoPt alloy comprising at least 4 to 30 at% of  
6 Pt, or a CoCrPt alloy, or CoCrPt-ZrO<sub>2</sub> or CoCrPt-SiO<sub>2</sub> further comprising 2 to 15 at% of Cr  
7 or a magnetic film having soft magnetic property containing Fe or Ni.

1 12. A magnetoresistive head according to any one of claims 1 to 8, wherein  
2 the magnetic domain control film is a stacked film having two-layers of magnetic films

antiferromagnetically coupled by way of a nonmagnetic film, and the magnetization film thickness product  $Br \cdot t$  of the magnetic domain control film is defined as

$$Br \cdot t = Br_1 \cdot t_1 - Br_2 \cdot t_2$$

assuming residual magnetic flux densities of the two layers of magnetic layers as  $Br_1$  and  $Br_2$ , respectively, and film thicknesses thereof as  $t_1$  and  $t_2$ , respectively.

13. A magnetoresistive head according to any one of claims 1 to 8, wherein the magnetic domain control film is a stacked film having three layers of magnetic films and antiferromagnetically coupled by way of a nonmagnetic film, and the magnetization film thickness product  $Br \cdot t$  of the magnetic domain control film is defined as

$$Br \cdot t = Br_1 \cdot t_1 - Br_2 \cdot t_2 + Br_3 \cdot t_3$$

assuming residual magnetic flux densities of the three magnetic layers as  $Br_1$ ,  $Br_2$ , and  $Br_3$ , respectively, and the film thicknesses thereof as  $t_1$ ,  $t_2$ , and  $t_3$ , respectively.

14. A magnetic head having a magnetoresistive head according to any one of claims 1 to 8 having as a reading head and having a writing head for in-plane recording.

15. A magnetic head having a magnetoresistive head according to any one of claims 1 to 8 as a reading head and having a writing head for perpendicular recording.